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19. ABSTRACT The objective of this work was to study the phase transformations and property changes of metals brought about by ion beam induced materials modification and then to use this information to produce stable surface layers exhibiting optimal chemical and mechanical integrity.

Summary of Most Significant Results:

1) Amorphous alloys can be formed by ion mixing a wide variety of metal systems within defined regions of atomic composition.

2) Two step processing such as implanting C and N into ion beam mixed layers improves the friction behavior.

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3) Fe-Ti mixed on stainless steel and implanted with N and C results in a wear resistant layer that deforms to depths greater than the thickness of the modified layer.

4) These novel structures on stainless steel were used to demonstrate a technique for distinguishing between deformation and material removal on worn surfaces.

5) Mixing substantial amounts of Au into Ti improves corrosion resistance of the Ti without appreciably degrading the wear and friction behavior.

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ION BEAM MODIFICATION OF METALS: MECHANICAL PROPERTIES AND STRUCTURE

Final Report to the U.S. Army Research Office

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Submitted by: Cornell Unversity
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Principal Investitgator: James W. Mayer James W Mayer

Final Report Written by: E. L. Fleischer E. L. Fleischer

Statement of the Problem Studied:

The objective of this work was to study the phase transformations and property changes of metals brought about by ion beam induced materials modification and then to use this information to produce stable surface layers exhibiting optimal chemical and mechanical integrity.

Summary of Most Significant Results:

1) Amorphous alloys can be formed by ion mixing a wide variety of metal systems within defined regions of atomic composition.

2) Two step processing such as implanting C and N into ion beam mixed layers improves the friction behavior.

3) Fe-Ti mixed on stainless steel and implanted with N and C results in a wear resistant layer that deforms to depths greater than the thickness of the modified layer.

4) These novel structures on stainless steel were used to demonstrate a technique for distinguishing between deformation and material removal on worn surfaces.

5) Mixing substantial amounts of Au into Ti improves corrosion resistance of the Ti without appreciably degrading the wear and friction behavior.

Discussion of Results:

Over the past several years we investigated hardness, friction, wear, and corrosion of ion beam mixed metal/metal systems and studied the resulting structural and compositional changes.

Our research (see list of publications acknowledging Army Research Office support) focused on the use of ion beams, both ion mixing and ion mixing plus ion implantation, to improve the wear and friction of stainless steels and titanium. The improvement in performance was dramatic in many cases.

Ion implantation has been used extensively to improve both mechanical and chemical properties of metals [1-3] . It has been shown that ion implantation in metals significantly reduces the friction coefficient and improves wear resistance. In applications, doses above 10^{17} ions/cm^2 are required to significantly alter surface compositions and to change mechanical properties. At these high doses sputtering sets the limit of composition achievable by ion implantation [4,5]. To overcome the composition limitation so as to reach the required high doses and to speed processing, ion beam mixing was used. By mixing deposited multilayer films into a metal substrate, one can obtain a homogeneous layer on stainless steel with good tribomechanical properties at doses as low as 10^{16} ions/cm^2. [6-8]

In our ARO supported work we have used four methods of ion beam modification to improve wear, friction, and corrosion of metals. The modes are: 1) direct ion implantation which is used to implant species such as carbon or nitrogen into the material at concentrations of a few atomic percent. 2) ion beam mixing which relies on the penetration of energetic ions through a deposited layer to cause intermixing between film and substrate. Single layer or multilayer deposited films are used to achieve the desired mixed composition . 3) ion-induced adhesion which is carried out by the penetration of energetic ion beams

past the film/substrate interface. The primary effect is to rearrange bonds at the interface to promote adhesion. Ion mixing between the film and substrate is minimal and the film must be deposited with the appropriate composition. 4) Two stage processing which uses ion mixing or ion-assisted adhesion to obtain an adherent film of the proper composition and a second implantation stage which introduces nitrogen or carbon into the modified layer to further improve mechanical properties. For stainless steel, two stage processing gave superior results compared to the one stage methods.

For example, nitrogen implantation was observed to significantly improve the dry sliding properties of an ion mixed FeTi surface alloy on stainless steel [9]. Two stage processing was also used in coevaporated films [10,11]. In this work, coevaporation of Pt and Ti on a stainless steel substrate produced a homogeneous film at the equiatomic composition. Adhesion of the evaporated film to the substrate was enhanced by a low dose ion implantation with light species, either Si or Ne. The tribomechanical properties were further improved by N implantation into the surface film.

We have shown that amorphous alloys can be formed by ion mixing in a wide variety of systems in defined regions of atomic compositions. Subsequent implantation even further improves the mechanical properties. The two stage process combined with layer-deposition allows the formation of layers with different composition and mechanical properties. That is, one can modify not only the surface layers, but also the intermediate layer between the surface region and the stainless steel substrate.

We found ion beam mixing substantial amounts of gold into titanium improves the corrosion resistance of the titanium without appreciably degrading the wear and friction properties [12]. The full range of compositions were measured by creating samples with linearly varying composition along the

length of the sample. This was accomplished by depositing alternating wedge shaped layers of Au and Ti and then ion mixing them. Reciprocal motion wear and friction tests across the composition gradient showed the variation of friction with composition. Likewise, the corrosion improvements for all compositions were compared on a single sample. Rutherford backscattering and transmission electron microscopy were used to correlate the property changes with composition and structure. A composition of 60%Ti-40%Au was chosen as optimal for improving corrosion resistance without appreciably degrading wear and friction properties. The microstucture consisted of a combination of crystalline and amorphous phases near the titanium end and of an fcc Au solid solution at the Au-rich end.

EDX line profiles (energy dispersive x-rays) combined with SEM (scanning electron microscopy) and Alpha Step surface profiles were used to distinguish between wear mechanisms such as deformation and material removal for surface layers with a different composition from the substrate. We used the ion beam modified steel samples as a model to demonstrate this simple, quick, and non-destructive method for distinguishing between the two processes. The samples were modified by mixing Fe and Ti on the surface and subsequently implanting C and N. The analysis technique is based on scanning an electron beam across the wear track while monitoring the characteristic X-ray emission from an element present only in the modified layer, Ti in our case [13]. This method correlates composition (indicating the amount of the modified layer remaining) to the physical contour of the wear track.

In the work at Cornell we used the facilities of the Materials Science Center for film deposition, scanning electron microscopy, and transmission electron microscopy. Ion implantation and Alpha Step profilometry was carried out at the National Nanofabrication Facility. Ion beam analysis was done using

the tandetron accelerator at Bard Hall. Wear and friction measurements were conducted on a Finnish designed (J.-P. Hirvonen) apparatus. Microindentation tests were carried out in collaboration with Prof. C.-Y. Li.

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